

Effects of Proton Center Closure on Pediatric Case Volume and Resident Education at an Academic Cancer Center

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Summary (75/75 words):

Changes in radiation oncology infrastructure influence referral/practice patterns and resident educational experiences. This study aimed to analyze effects of closure of an academic proton treatment center (PTC) on pediatric case volume, distribution, and resident education. We demonstrate a sharp decrease in overall pediatric cases and potentially curable CNS tumors treated at our center following PTC closure. Our findings raise important questions regarding resident training in pediatric radiation oncology as these cases become concentrated at specialized centers.

Abstract

Purpose: Changes in radiation oncology infrastructure influence referral/practice patterns, which may affect resident educational experiences. This study aimed to analyze effects of closure of an academic proton treatment center (PTC) on pediatric case volume, distribution, and resident education.

Methods: This was a review of 412 consecutive pediatric (≤ 18 years) cases treated at a single institution from 2012-2016. Residents' Accreditation Council for Graduate Medical Education case logs for the same years were also analyzed. Characteristics of the patient population and resident case volumes before and after closure of the PTC are reported.

Results: Overall pediatric new starts declined by about 50%, from 35-70 per 6 months in 2012-2014 to 22-30 per 6 months in 2015-2016. CNS case volume declined sharply, from 121 patients treated in 2012-2015 to 18 patients in 2015-2016. In 2012-2014, our institution treated 36, 24, and 17 patients for medulloblastoma/intracranial PNET, ependymoma, and low grade glioma (LGG), respectively, compared to 0, 1, and 1 patients in 2015-2016. 49 patients were treated with craniospinal radiation (CSI) from 2012-2014, while only 2 patients underwent CSI between 2015-2016. Hematologic malignancy patient volume and use of total body irradiation remained relatively stable. Patients treated when the PTC was open were significantly younger (9.1 vs 10.7 years, $p=0.070$) and their radiation courses were longer (35.4 vs 20.9 days, $p<0.0001$) than those treated after its closure. Resident case logs showed only a small decline in total pediatric cases, as the percentage of pediatric cases covered by residents increased after PTC closure; however, residents logged fewer CNS cases after PTC closure vs. before.

Conclusions: Overall pediatric case volume decreased following PTC closure, as did the number of patients treated for potentially curable CNS tumors. Our findings raise important questions regarding resident training in pediatric radiation oncology as these cases become increasingly concentrated at specialized centers.

Introduction

Approximately 12,000 children and adolescents are diagnosed with cancer annually in the US [1], around 3,000 of whom receive radiation therapy (RT)[2]. Compared with photon RT (XRT), proton beam therapy (PBT) decreases dose to nearby organs at risk (OAR), reduces integral dose, and may reduce acute and late toxicities as well as secondary malignancies[3]. PBT has therefore gained increasing acceptance in the treatment of pediatric solid tumors[4]. In patients who require craniospinal irradiation (CSI), PBT can spare anterior OARs including the heart, lungs, esophagus, chest wall, gastrointestinal tract, and breasts[5, 6]. There is also sound rationale for PBT in the treatment of central nervous system (CNS) and ocular malignancies, given the risk of serious neurologic sequelae such as cognitive dysfunction and hearing loss in children who undergo brain irradiation[6-8]. PBT may also provide a dosimetric advantage in certain sarcomas, such as orbital and genitourinary rhabdomyosarcoma, mostly due to sparing of proximal OARs[9, 10]. The clinical advantages of PBT over XRT may decrease when low doses are administered, when large, nonconformal fields are treated, or in palliative cases[11]. Additionally, XRT remains standard for total body irradiation (TBI) before stem cell transplant.

Nationwide, PBT utilization continues to rise, increasing by 33% for all pediatric cancers between 2010-2012[12]. A recent National Cancer Database study reported that although <1% of children with CNS tumors received PBT in 2004, this had increased to 15% by 2012[13]. As of this writing, there are 25 US proton treatment centers (PTC), up from 14 in 2014[14, 15]. Our institution (the Department of Radiation Oncology at [redacted]) has had a unique experience with its PBT service. In the 1940's, [redacted] constructed a research cyclotron at its main campus in [redacted]. This particle accelerator was subsequently renovated and converted into a facility capable of delivering clinical PBT, which opened in 2004 as the [redacted][16]. Because of concerns about

financial sustainability, particularly related to the cost of repair and replacement of the facility's equipment, the [redacted] stopped accepting new patients in October 2014 and was permanently closed in December 2014.[17] It remains the only proton center associated with an academic health system to close without being replaced. We hypothesized that the closure of the PTC would be associated with significant alterations in the number and distribution of pediatric cases treated within our department and that the PTC closure might affect resident education in pediatric cancers. The goal of the present study was to quantify changes in pediatric case volume due to the PTC's closure and to describe how these changes affected resident training.

Methods

Program Setting, Patient Selection, and Data Reporting

This study was conducted at a single academic radiation oncology department with an ACGME-accredited radiation oncology residency program. At the time of this writing, the program had 8 residents and 9 full-time clinical faculty members. A single faculty member maintained a dedicated pediatric service while the proton center was open as well as during and after its closure. Residents were periodically assigned to the PTC as a unified rotation but not specifically to the pediatric service. After the PTC closed, the resident rotation schedule was changed to its present structure, which ensures that a dedicated resident is assigned to the pediatric service.

After approval was obtained from our internal institutional review board, the electronic medical record was queried for all patients aged ≤ 18 years who received RT in our department between 1/1/2012-12/31/2016. Case volumes are reported over 6-month blocks before and after the PTC closure in order to minimize bias due to month-to-month variability in case loads for relatively rare diagnoses. Differences in patient volume, age, and treatment duration were analyzed

using a two-tailed T test for unequal variance. Results are reported according to the following diagnostic groups: CNS tumors [high- (HGG) and low-grade (LGG) gliomas, medulloblastoma/supratentorial primitive neuroectodermal tumor (PNET), ependymoma, and intracranial germ cell tumors (ICGCTs)]; non-CNS solid tumors [Wilms tumor (WT) and neuroblastoma]; sarcomas [Ewing's/bone sarcoma, rhabdomyosarcoma, and other soft tissue sarcoma (STS)]; lymphomas [Hodgkin (HL) and non-Hodgkin lymphoma (NHL)]; and leukemias.

Resident Case Logs; In-Training Examination Scores

To analyze the PTC closure's effects on resident training, we reviewed case logs completed by all residents in our training program between 1/1/2012-12/31/2016 using the Accreditation Council for Graduate Medical Education's online system, which collects details on each case planned by residents, including date of treatment, diagnosis, and type of case (pediatric vs adult). We also collected percentile scores for all of our program's residents on the Pediatrics section of the American College of Radiology In-Training Exam from 2012-2016.

Results

Patient Volume, Demographics, and Radiation Technique

During the study period, 412 radiation courses were delivered in 388 individual patients (Table 1); 199 and 213 courses were delivered with PBT and XRT, respectively. Fifty-one patients underwent CSI, 37 had TBI, and 7 underwent stereotactic radiosurgery (SRS), primarily for AVMs. RT was delivered for benign indications in 33 cases. The volume of pediatric cases treated within our department dropped sharply after the PTC closed (mean 50.7 pediatric cases per 6-month block before closure vs 27.0 per 6-month block after closure, $p = 0.005$). In the six 6-month blocks from January 2012 through December 2014, there were 56, 70, 47, 48, 48, and 35 cases (Figure 1);

199/304 (65.5%) children underwent PBT during this period. In the four 6-month blocks following the PTC closure, the number of pediatric cases decreased to 29, 22, 30, and 27. Additionally, after the PTC closed, the mean age of pediatric patients treated in our department increased [9.1 years (range 0.71-18.80 years) vs 10.7 years (range 0.23-18.91 years) for patients treated from 2012-2014 vs 2015-2016, respectively; $p=0.010$, *Table 1*]. Mean treatment duration decreased after the PTC closed [35.4 days (range 1-92 days) vs 20.9 days (range 1- 56 days) for 2012-2014 vs 2015-2016, respectively ($p<0.001$)]. Similarly, non-CNS solid tumors treated after the PTC closed received a shorter RT course than those treated before [(mean 36.3 vs. 22.9 days, $p<0.001$)]. There was a trend towards shorter treatment duration for CNS tumors after PTC's closure (mean 44.5 days vs 39.0 days); however, given the paucity of patients with CNS tumors treated after 2015 this was not statistically significant ($p= 0.14$).

Changes in Diagnoses and Treatment

Before the PTC's closure, CNS malignancies comprised 39.8% of pediatric cases but represented 16.7% of cases afterwards (Figure 2). Medulloblastoma/intracranial PNET and ependymomas comprised almost half of the CNS tumors treated when the PTC was open; only one of these tumors, an ependymoma, was treated after its closure. After the PTC closure, HGG comprised the majority (61.1%) of CNS cases, compared to 26.5% beforehand.

Case volumes of craniopharyngioma and LGG also declined sharply after 2014 (Figure 3B). On average, 1.3 patients with craniopharyngioma (range 1-3) and 2.8 patients with LGG (range 1-8) underwent PBT per 6-month block between 2012-2014; however, no cases of craniopharyngioma and only one LGG were treated in 2015-2016. Case volumes for HGG and ICGCT also decreased, but not as dramatically (Figure 3B); a mean of 5.2 (range 1-11) and 2 (range 0-5) patients with HGG and ICGCT, respectively, were treated from 2012-2014 per 6-month block, compared to 2.8 (range

1-4) and 1 (range 0-2), respectively, after the PTC's closure. The number of patients treated for hematologic malignancies did not change greatly, with a mean of 2.8 (range 1-5) cases of HL and 5.2 (range 2-7) cases of leukemia treated per 6-month block prior to the PTC's closure, compared to post-closure means of 3 (range 1-4) and 4.5 (range 2-6), respectively. WT [pre-closure mean 3.5 (range 1-8) vs post-closure mean 3 (range 2.5) cases per 6 months] and neuroblastoma (pre-closure mean 2.8 (range 2-4) vs post-closure mean 2.5 (range 1-5) cases per 6 months) caseloads also remained relatively stable. Prior to the PTC closure, an average of 11 (range 6-19) pediatric sarcoma patients were treated per six-month block, with the majority receiving PBT (Figure 3B). Although sarcoma case volume decreased after the PTC closed, an average of 5.8 (range 4-8) patients with sarcoma continued to be treated with XRT per six-month block.

There were 13, 8, 7, 3, and 3 CSI treatments in the six 6-month blocks from January 2012 through December 2014; only 2 pediatric patients have undergone CSI in our department since the PTC closed (Figure 4). Overall, 47/51 (92.2%) of CSI patients received PBT. The number of patients treated with TBI did not change, as XRT-based TBI has always been standard in our department.

Resident Case Logs and In-Training Exam Performance

Residents logged 206 pediatric cases from 2012-2016 (Figure 5). From 2012-2014, 118 pediatric cases were logged [mean 19.7 (range 4-32) cases per 6-month block], compared to 86 cases from 2015-2016 [mean 21.5 (range 14-27) cases per 6-month period]. Residents logged an average of 37.1% (range 11.4%-57.4%) of the institution's pediatric cases per 6-month block prior to PTC closure, compared to 80.6% (range 46.7%-96.3%) afterwards. There were 34 CNS (non-medulloblastoma), 21 leukemia, 25 sarcoma, 20 non-CNS solid tumors, 9 lymphoma, and 5 medulloblastoma cases logged from 2012-2014, compared to 17 CNS (non-medulloblastoma), 12

leukemia, 23 sarcoma, 20 non-CNS solid tumors, 10 lymphoma, and 0 medulloblastoma cases logged after the PTC closed. CNS tumors (medulloblastoma and non-medulloblastoma) comprised 33.1% and 19.8% of resident cases before and after the PTC closed, respectively, while the proportion of other diagnoses remained relatively stable (Figure 5). Pediatric inservice exam scores also dropped after the PTC closed, although the difference was not statistically significant (mean percentile rank 54.0 from 2012-2014 vs 41.4 in 2015-2016, $p = 0.12$).

Discussion

This is the first report to describe the effects of PTC closure on pediatric caseloads at an academic center with a radiation oncology residency. The closure of the PTC resulted in an approximately 50% decrease in our pediatric case volume, as well as a remarkable shift in the types of patients treated in our department, with the largest decreases seen in diagnoses with the greatest anticipated clinical benefit of PBT, such as potentially curable CNS tumors and sarcomas. A smaller decline in the number of HGG patients treated was observed, as would be expected in diseases such as diffuse intrinsic pontine glioma or glioblastoma, where the clinical benefit of PBT compared with XRT is less clear. With the decrease in definitive CNS cases, we observed a sharp decline in the number of CSI plans delivered in our department after the PTC closed, which may be due to several factors, including growing acceptance of PBT as the standard of care for pediatric patients who require CSI[18]. Additionally, since all pediatric solid tumor cases treated at our institution are discussed prior to treatment in multidisciplinary tumor boards, our pediatric radiation oncologists may suggest direct referral to a proton center (rather than consultation in our department) in order to expedite treatment. Our sarcoma case volume also declined, but to a lesser extent than CNS tumors. Sarcomas are heterogeneous in terms of both histology and anatomic site, and the

presumptive advantage of PBT varies. For example, the presumed benefit of PBT over XRT may be greater for a skull base chordoma than an extremity rhabdomyosarcoma[19].

Unlike CNS tumors and sarcoma, case volumes for hematologic malignancies and non-CNS solid tumors remained relatively stable. These patients are typically treated with lower total doses and less conformal fields than CNS and head/neck tumors, reducing the expected benefit of PBT. For example, patients with WT who require low-dose radiation to the flank, whole abdomen, whole lung, or liver would be anticipated to derive little additional clinical benefit from PBT[11]. Similar considerations apply to patients with HL and neuroblastoma.

We also observed that between 2012-2014, mean patient age was significantly lower, and the treatment duration was significantly longer, compared to 2015-2016. The age differential is likely due to the shift of diagnoses away from CNS tumors and towards lymphoma, as lymphomas tend to be more common in adolescents[1]. The shorter course length after the PTC closure is likely due partly to the decreasing number of CNS tumors, since many patients with CNS tumors receive 4-6 weeks of radiation compared to 2-4 weeks for patients with diagnoses such as WT and HL. Also, a greater proportion of patients may have been treated with palliative intent after 2015, although we were unable to collect specific data regarding treatment intent in this study. To better account for the shift in diagnoses from CNS to hematologic malignancies, course length for only non-CNS solid tumors (sarcoma, WT, and neuroblastoma) was analyzed. There was a similar decline in treatment duration in this cohort, suggesting more of these patients were treated palliatively.

The total number of pediatric cases logged by residents declined only slightly after the PTC closure, although the case logs still reflect a large decline in the pediatric CNS case volume treated in our department. This observation is likely due to factors specific to our cancer center. The PTC was located in [redacted], which is approximately 50 miles from our main cancer center in [redacted].

Although residents were periodically assigned to the PTC, the majority of cases treated there did not have resident involvement in the treatment planning process. In contrast, most academic PTCs are closer to the main teaching site [20], which may result in residents being able to log a higher proportion of pediatric PBT patients. After the PTC closed, all pediatric patients have been treated at our main cancer center in [redacted], and we now mandate full-time resident coverage of the pediatric service. Both of these changes have allowed residents to log a higher proportion of pediatric cases. However, the relative stability in case numbers was a result of structural factors unique to our program, and our overall case volume does not appear to be an adequate metric for the distribution of cases available for resident education, since case volume remained the same while the number of definitive CNS cases available for resident education declined dramatically. This change could only be identified with a detailed review of our resident case logs. Similar to the overall departmental trend, resident case logs reflected the decreasing number of patients with CNS tumors (39 cases logged from 2012-2014 vs 17 from 2015-2016) and the absence of medulloblastoma cases. Although special techniques are not itemized in the case log system, only two CSI cases were available for resident education in 2015-2016 (Figure 4).

The challenges of providing adequate training in pediatric radiation oncology have been well described and are related to low patient numbers, the concentration of pediatric cancer care within large specialized centers, and the complexity and diversity of pediatric cancers[21-23]. These issues are not unique to our institution; the limited availability of PBT has likely amplified the ongoing trend of concentrating pediatric radiation cases at specialized institutions[10]. Current ACGME requirements stipulate that all residents must plan at least twelve pediatric cases over a four-year residency. This requirement has remained unchanged in the face of an ever-increasing number of residency positions nationwide and longstanding evidence that the distribution of pediatric case volume is decidedly inhomogeneous and likely becoming more so[13, 22]. A 2013 paper estimated

that radiation oncology residents would be expected to see an average of 4.6 pediatric cases per year, assuming that all pediatric patients are treated at academic centers with radiation oncology residency programs and that pediatric case volume is distributed homogeneously among all centers (assumptions which are clearly incorrect)[22]. Since that paper was published, the number of radiation oncology residency positions has increased, with a total of 746 slots filled in the National Resident Matching Program in the past 4 years[24]. Assuming that total pediatric case volume has remained relatively constant over the past three years, the average number of pediatric cases per resident has decreased to 3.4 cases annually (or a total of 13.6 cases over the four-year residency). Given these numbers, residents in programs that treat few children are almost certain to have to consider alternative opportunities, most likely away rotations, in order to fulfill their training requirements. Graduating residents are well aware of these challenges, with 49.3% of respondents in a recent survey reporting “no or inadequate level of exposure” to pediatric diseases[25]. Furthermore, it remains unclear whether the graduation requirement for planning 12 pediatric cases confers true expertise in treating these cancers[23]. It is concerning that if the trends described in this report continue, most graduating residents at our institution are unlikely to treat patients with ependymoma, medulloblastoma, LGG, or ever set up CSI fields; however, they would still meet their pediatric case requirements for independent practice. It is logical to conclude that many programs without access to a PTC would face similar deficits in training, especially in the treatment of pediatric CNS malignancies.

Most critically, outcomes in childhood cancer appear to be optimized when treatment is offered at high-volume institutions[26, 27]. Specialized pediatric cancer centers offer expertise in the medical management of childhood cancers and access to clinical trials, as well as multidisciplinary care including pediatric-focused behavioral, rehabilitation, and psychosocial support services, all of which are unlikely to be available at cancer centers that primarily treat adult patients. Certainly the

pedagogical demands of radiation oncology residency training should not be prioritized over providing the best possible care to children with cancer. If the clear advantage of concentrating pediatric oncology care within specialized high-volume centers of excellence decreases the ability of some residency programs to provide adequate exposure to the full spectrum of pediatric cancers, how can we adjust resident training to compensate? One potential solution is additional subspecialty or fellowship training in pediatric radiation oncology. Unfortunately, experts in the field have assessed that American Board of Medical Specialties endorsement of pediatric radiation oncology fellowships is unlikely due to the small projected number of potential training programs and reluctance to shift the pediatric experience out of core radiation oncology training[22]. Two existing pediatric fellowships remain non-ACGME accredited given the above concerns[28]. Other options for enhancing resident education in pediatric oncology include improving access to elective rotations at high-volume pediatric centers or providing universal access to case simulations designed and evaluated by experts in pediatric oncology.

Our results are limited by the fact that this is a study of a unique experience (the closure without replacement of a large regional referral center for proton therapy), and it is unknown whether our experience can be extrapolated to other settings. Second, the decrease in pediatric volume was likely not solely due to the PTC's closure. When our center first began treating patients in 2004, it was the only proton center in the Midwest. However, over time, additional proton centers have opened in the Midwest, and at this writing, there are seven proton facilities within a 500-mile radius of our hospital (Figure 1) [15, 20, 29-35]. These additional centers may have decreased our patient volume regardless of the PTC's status.

Despite these limitations, our experience clearly demonstrates that pediatric case volume and distribution within an academic radiation oncology department will vary based on available

technology and referral base. PTC closure led to a large drop in the number of pediatric CNS cases treated in our department. This may have compromised resident education in pediatric malignancies, although our residents still fulfilled their required case numbers for graduation. Given the complexity of pediatric oncology, we agree that most children with cancer should be cared for at high volume centers[22] and recognize that this will limit the clinical experiences of residents at some training programs. Nonetheless, it is necessary to guarantee that all radiation oncology residents receive sufficient training in pediatric cancers in order to ensure that patients who cannot be treated at centers of excellence still receive adequate care.

Conclusions

The volume of pediatric cases treated at our institution decreased after the closure of a proton therapy center, with the most dramatic decline seen in CNS tumors. Although the total number of pediatric cases logged by residents remained relatively stable, the closure of the proton center resulted in a substantial reduction in our residents' clinical exposure to several fundamental pediatric cancers, most importantly CNS tumors such as ependymoma, LGG, and medulloblastoma. Continued study is needed regarding how to fulfill the critical goals of optimizing pediatric radiation oncology care while providing adequate clinical training in the treatment of childhood cancers.

Figure Legends

Table 1. Characteristics of pediatric patients treated at our institution before (2012-2014) and after (2015-2016) the proton center's closure. PT: proton therapy.

Figure 1. Total pediatric cases treated at our institution, divided into 6-month blocks and by treatment modality. The green line shows the number of other proton centers within 500 miles of

our institution; the shaded area represents the period (2012-2014) when our proton center was open.
Red bar: photon treatments; blue bar: proton treatments

Figure 2. Distribution of pediatric cases before (2012-2014) and after proton center closure (2015-2016). Subtypes of CNS tumors are shown to the right of the respective charts, and the total number of cases treated during that era is listed after the group name. CNS: central nervous system; Medullo: medulloblastoma; RB: retinoblastoma; LGG: low grade glioma; HGG: high grade glioma; PNET: primitive neuroectodermal tumor

Figure 3a. Total number of new patient starts in our department over time. Blue line: CNS tumors; red line: non-CNS solid tumors; green line: leukemia/lymphoma. **Figure 3b.** Number of new starts by specific diagnosis, divided into 6-month blocks. Red bar: photon treatments; blue bar: proton treatments. The shaded area in both panels denotes the period (2012-14) when the proton center was open. Benign intracranial lesions include arteriovenous malformations, pituitary adenomas, craniopharyngioma, and meningioma. LGG: low grade glioma; HGG: high grade glioma; PNET: primitive neuroectodermal tumor.

Figure 4. Cases of craniospinal radiation and total body irradiation, divided into 6-month blocks and by treatment modality. Red bar: photon treatments; blue bar: proton treatments.

Figure 5a. Pediatric cases logged by our residents. Bar represents total cases logged by residents, and line represents the percentage of total pediatric cases logged by residents. The shaded area denotes the period (2012-14) when the proton center was open. **Figure 5b.** Distribution of pediatric cases logged by residents before (2012-2014, left) and after PTC closure (2015-2016, right). Total number of cases treated during that era listed after group name. CNS: central nervous system.

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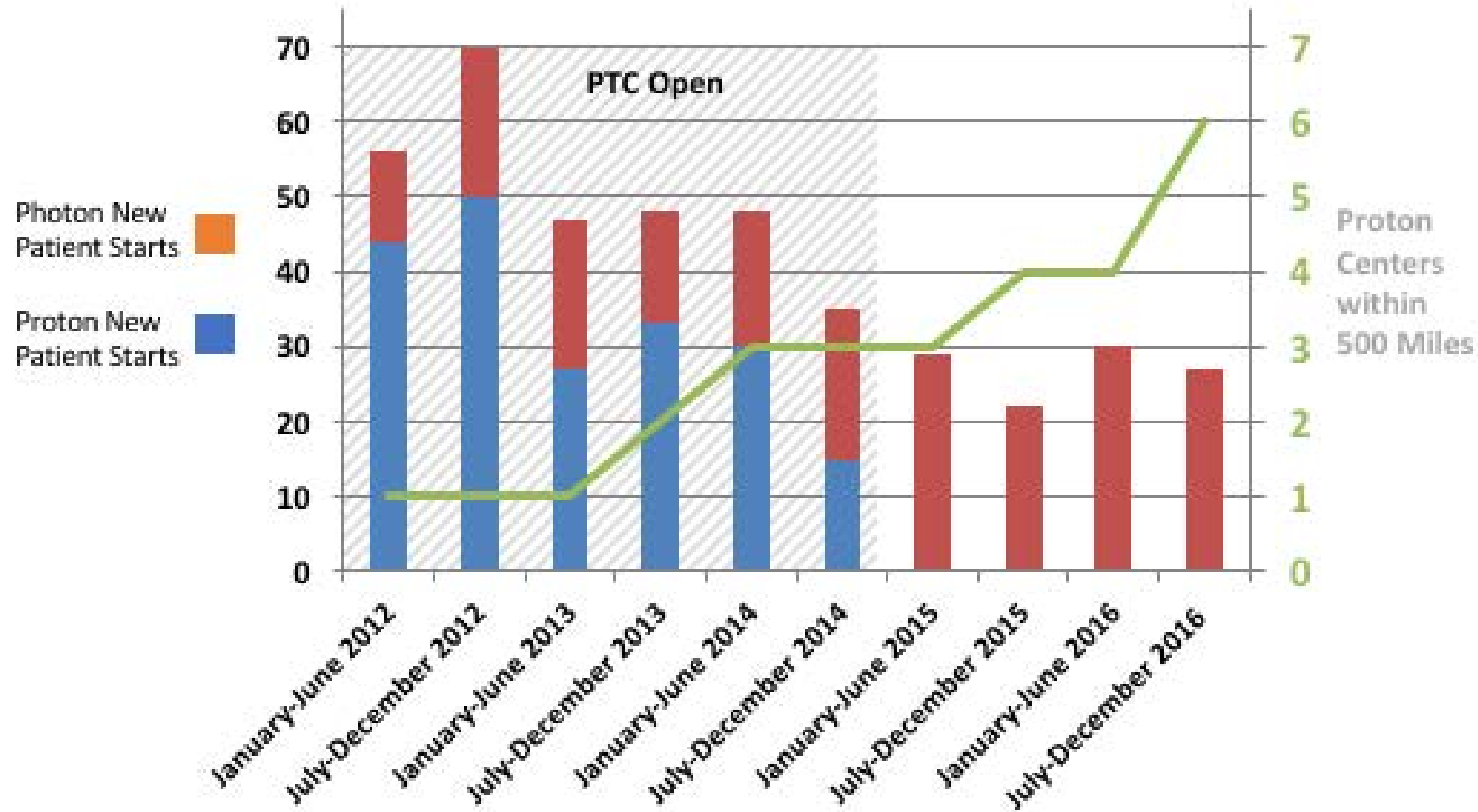
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Table 1. Patient characteristics before (2012-2014) and after (2015-2016) the proton center's closure.

Year	2012-2014	2015-2016	<i>P</i>
Number of courses	304	108	
Courses treated with proton therapy, n (%)	199 (65.5)	0 (0)	
Mean patient age (years)	9.1	10.7	0.01
Mean treatment duration (days)	35.4	20.9	<0.0001

Figure 1



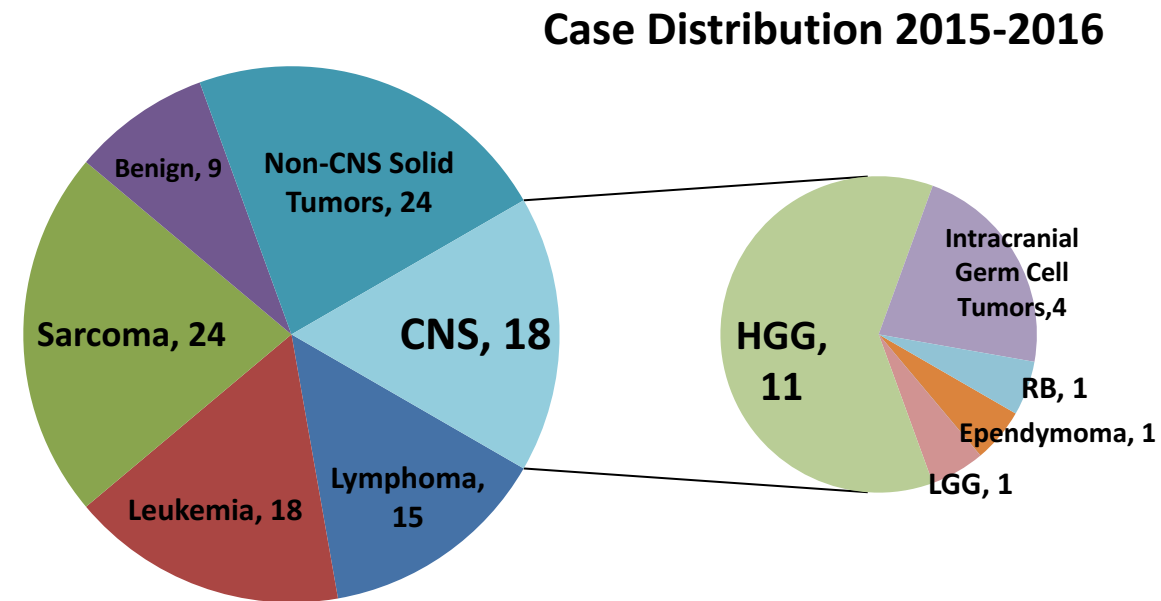
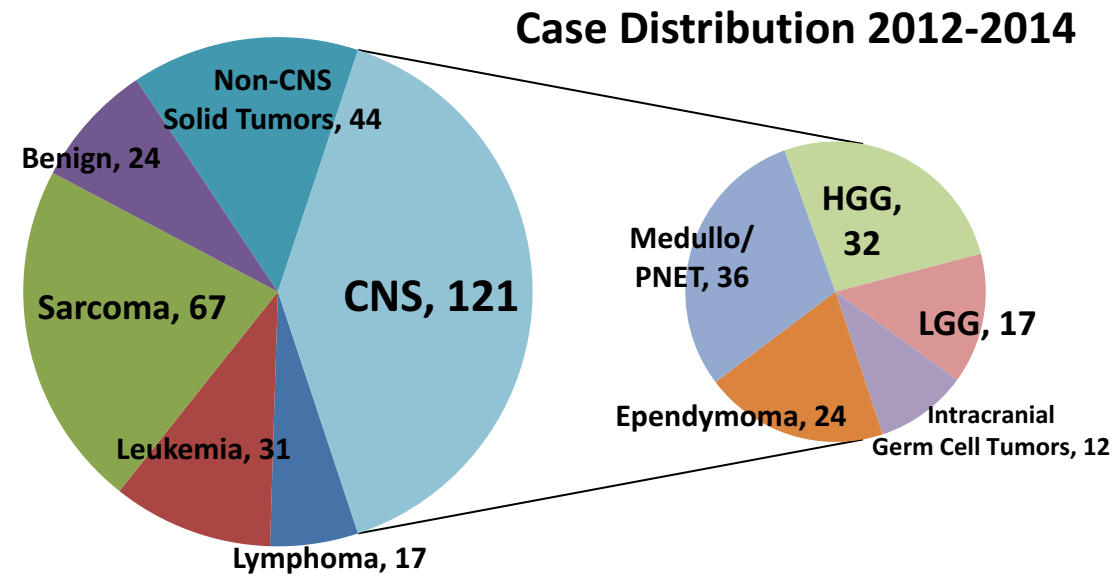


Figure 2. Distribution of pediatric cases before (2012-2014) and after proton center closure (2015-2016). Total number of cases treated during that era listed after group name. Medullo- Medulloblastoma; RB- Retinoblastoma.

Figure 3a

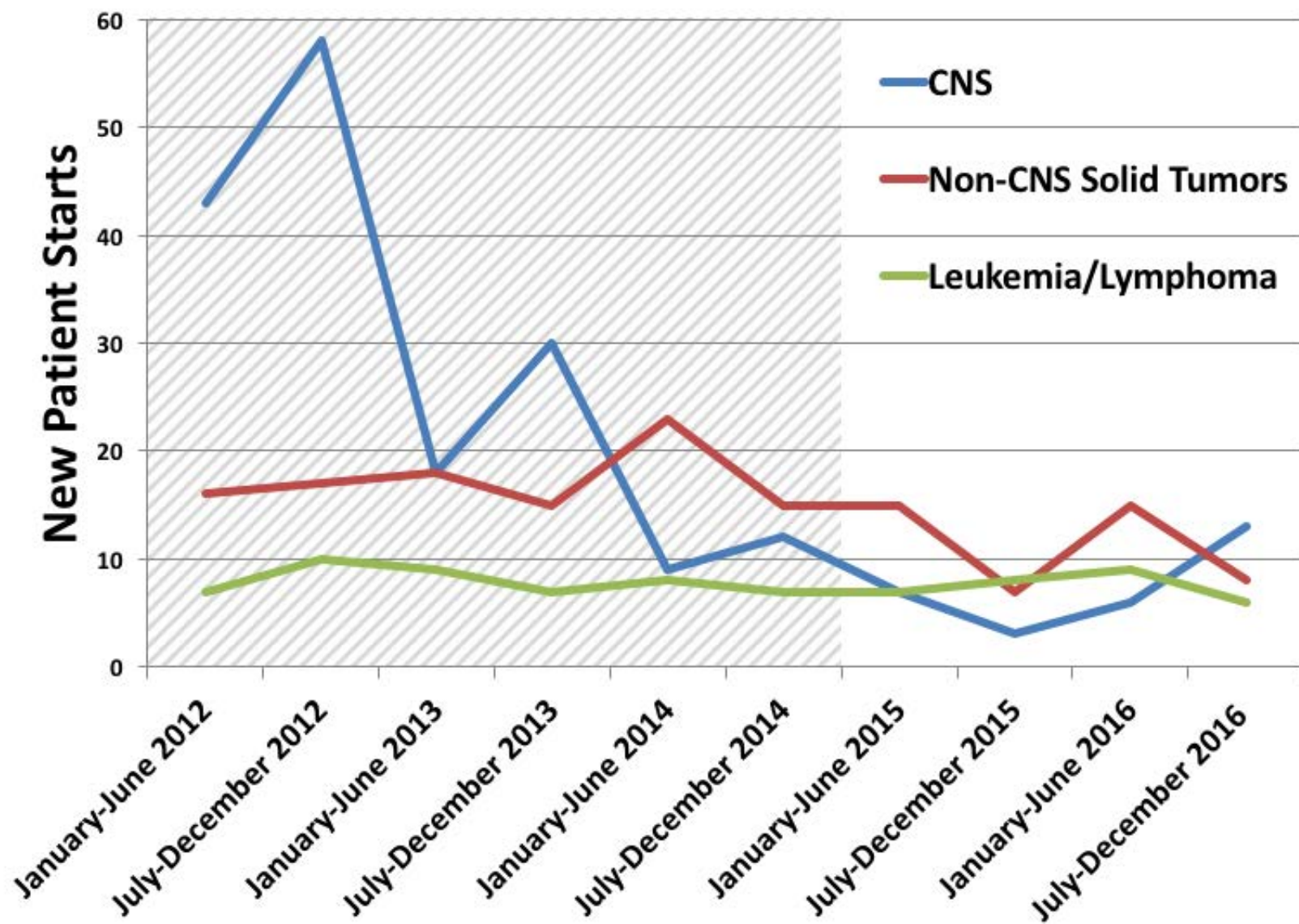


Figure 3b

■ Photon New Patient Starts
■ Proton New Patient Starts
▨ Proton Center Open

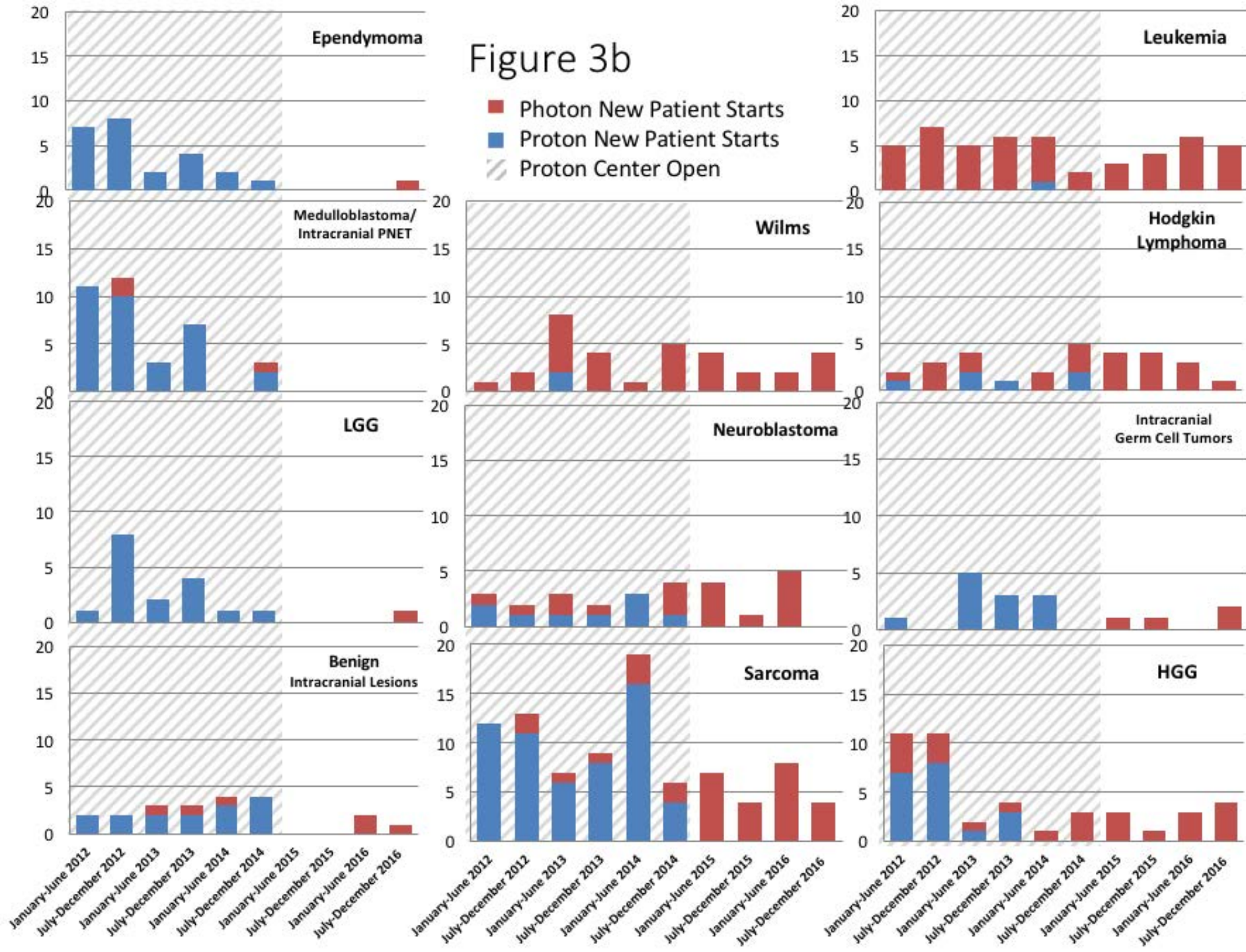


Figure 4

